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PERFORMANCE EVALUATION OF PRE-CAST SLABS FOR CONTINGENCY RIGID AIRFIELD PAVEMENT DAMAGE REPAIR

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MATERIALS AND MANUFACTURING DIRECTORATE

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14. ABSTRACT

Draw backs of cast in-place include: a) weather window essential for operations might not be available b) several days of closure. Advantages of Pre-cast include: can be completed in about 6 hours, more control on material properties of the precast concrete, texturizing the surface for tire-pavement interaction. Draw backs of Pre-cast: cost (1.6 to 4 times higher), Transportation of the panels. This study investigates the feasibility and the efficiency of using different precast concrete panel installation techniques. High density polymer (HDP) foam and flowable fill were selected as the leveling materials after literature review. The precast panels were installed using three installation techniques (conventional injection, deep injection and flowable fill) to study their impact on the performance of the repaired sections characterized by load transfer efficiency, joint stiffness and deformation energy dissipated through the pavement foundation.

15. SUBJECT TERMS

pre-cast concrete, concrete panels, airfield pavement damage, airfield repair, airfield rigid pavements

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PERFORMANCE EVALUATION OF PRE-CAST SLABS FOR CONTINGENCY RIGID AIRFIELD PAVEMENT DAMAGE REPAIR

October 26, 2010

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Outline

- **Objectives**
- **Background**
- **Installation Techniques and Materials**
- **Application of HWD for:**
  - Back-Calculation of Layer Moduli
  - Analysis of LTE
  - Analysis of Joint Stiffness
  - Analysis of Deformation Energy
  - Analysis of the Synergistic Effect of Aging and Temperature
    - Back-Calculation of Layer Moduli
    - Analysis of LTE
    - FE Analysis of Pre-cast Panels
    - Performance Index for Pre-cast panels
- **Conclusions**

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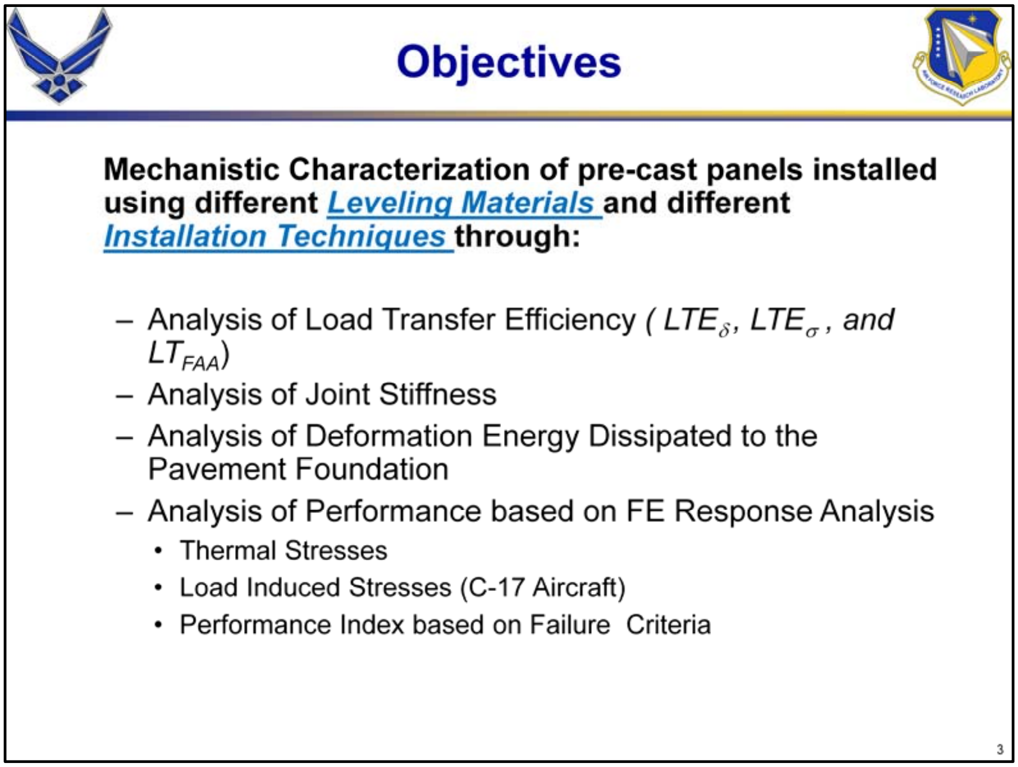
Repair methodologies: 1) cast in-place/high early strength materials 2) Pre-cast panels

Drawbacks of cast in-place include: a) weather window essential for operations might not be available b) several days of closure

Advantages of Pre-cast include: can be completed in about 6 hours, more control on material properties of the precast concrete, texturizing the surface for tire-pavement interaction
Drawbacks of Pre-cast: cost (1.6 to 4 times higher), Transportation of the panels

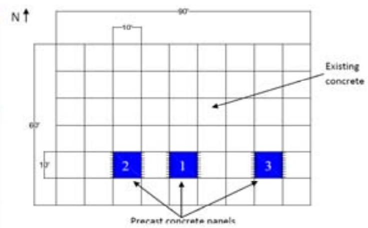
This study investigates the feasibility and the efficiency of using different precast concrete panel installation techniques. High-density polymer (HDP) foam and flowable fill were selected as the leveling materials after literature review. The precast panels were installed using three installation techniques (conventional injection, deep injection and flowable fill) to study their impact on the performance of the repaired sections characterized by load transfer efficiency, joint stiffness and deformation energy dissipated through the pavement foundation.



Heavy Weight Deflectometer and F-15 gear simulator were used to determine the stiffness properties and accumulation of plastic deformations after each load interval. Decay of joint stiffness and load transfer efficiency as well as increase in deformation energy were calculated as a function of number of load applications.

Objective is to provide a comparative study to select best bonding agent-installation technique that results in the highest performance.

Variant	Pre-cast Panel ID.	Joint Orientation	Bonding Agent	Installation Method	HWD Direction
1	#1	East	HDP Foam	Direct Injection	East to West
2	#1	West	HDP Foam	Direct Injection	East to West
3	#2	East	HDP Foam	Deep Injection	East to West
4	#2	West	HDP Foam	Deep Injection	East to West
5	#3	East	Flowable Fill	Conventional	West to East
6	#3	West	Flowable Fill	Conventional	West to East
7	#3	East	Flowable Fill	Conventional	East to West
8	#3	West	Flowable Fill	Conventional	East to West



Three precast concrete panels were installed on the PCC test-pad at Air Force Research Laboratory (AFRL). The test pad consisted of 12-inches-thick steel-reinforced PCC. Each precast concrete repair panel was 9-inches thick. The precast panels contained steel reinforcement to prevent damage during the transportation and installation operations as well as mitigating thermal cracking.

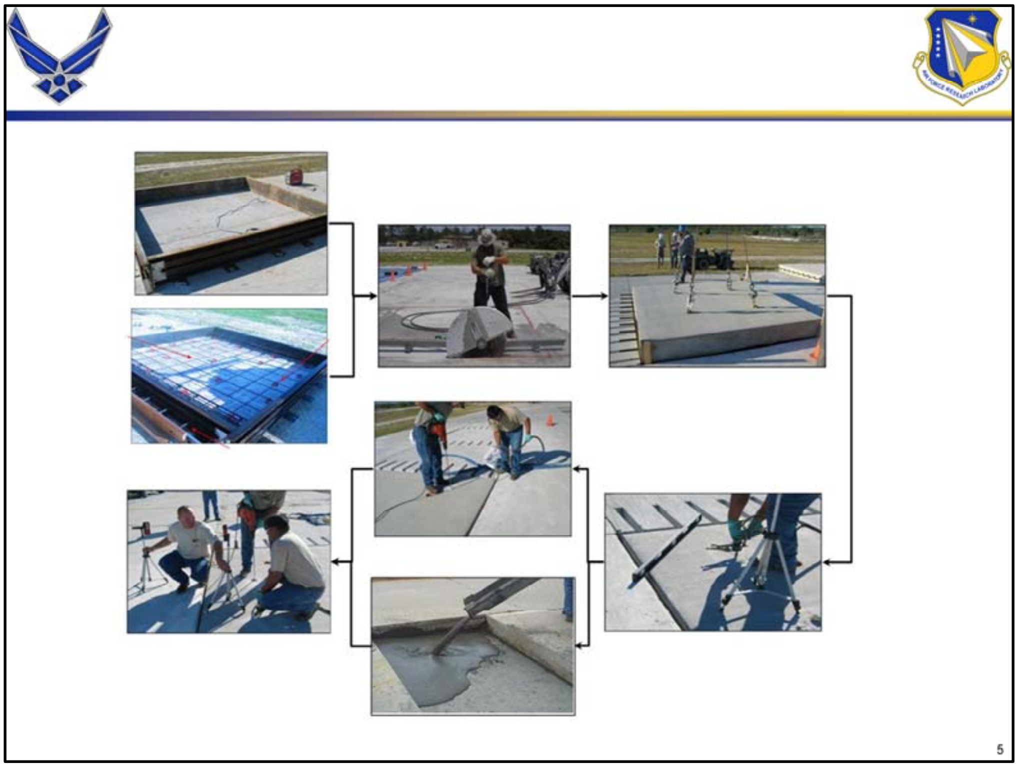
Three installation techniques (conventional HDP foam injection, deep HDP foam injection and conventional flowable fill) were studied in this research. The HDP foam is able to spread underneath the precast concrete panel and enhance stiffness properties of the foundation. As the foam spreads it undergoes chemical reactions causing it to expand. The foam exerts an upward lift under the pre-cast panel forcing it in an upwards direction. The primary role of leveling materials was assumed to provide proper adhesion between the pre-cast slab and the foundation so as to eliminate residual shear stresses created due to slippage at the interface of layers. Bonding agents also act as leveling materials in the installation process of the repaired panels.

The second method studied in this paper was deep injection of HDP foam into the subgrade soil. This process entails drilling portholes through the precast panel at several feet into the sub-grade. The high density foam is then infused into the subgrade material, stabilizing and therefore enhancing the mechanical properties of the soil matrix.

Multiple injection ports and precise leveling equipment were considered to ensure that the precast repair panel is even with the adjacent concrete slab. The injection ports are grouted after successfully leveling the precast panel.

The third method is the conventional leveling of the slabs using a cementations flowable fill. Each precast panel incorporated load transfer dowels installed prior to concrete placement. Dowel slots were cut into the existing concrete slabs.

Table 1 presents the permutations of the experiment design. Three installation techniques and two bonding agents were used to install the pre-cast panels. The position of the loading frame and the direction of the sensors are also indicated in this table.

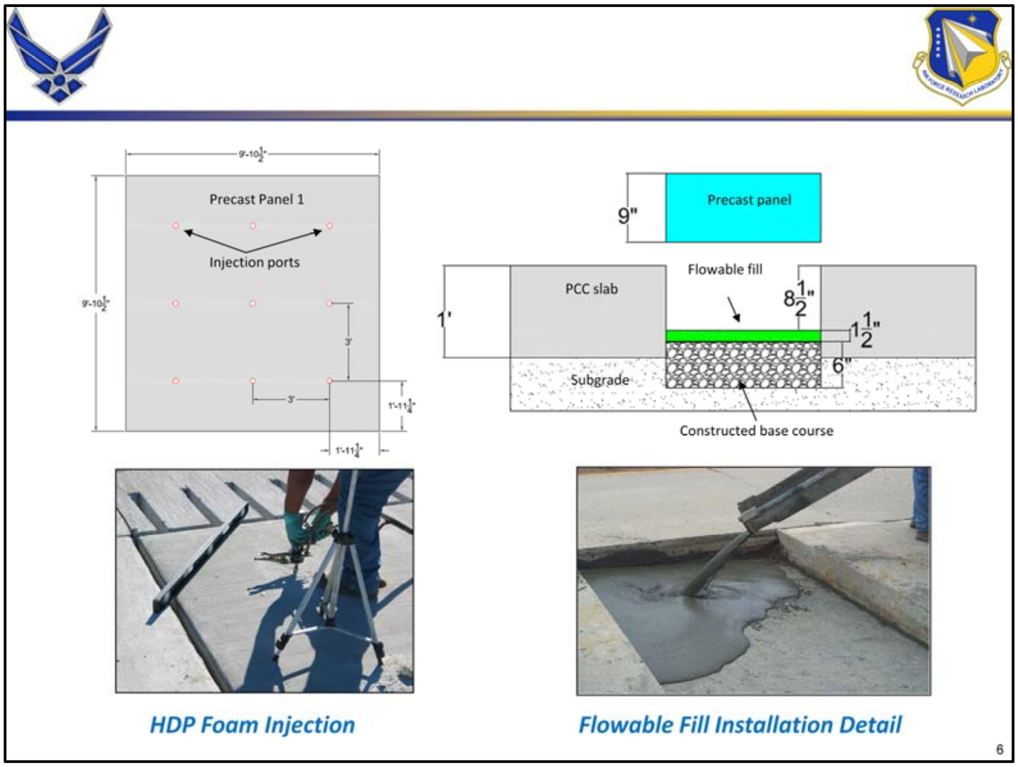


-Slab removal (lift out: saw cutting into manageable pieces) and shattering: breaking into small blocks and remove.

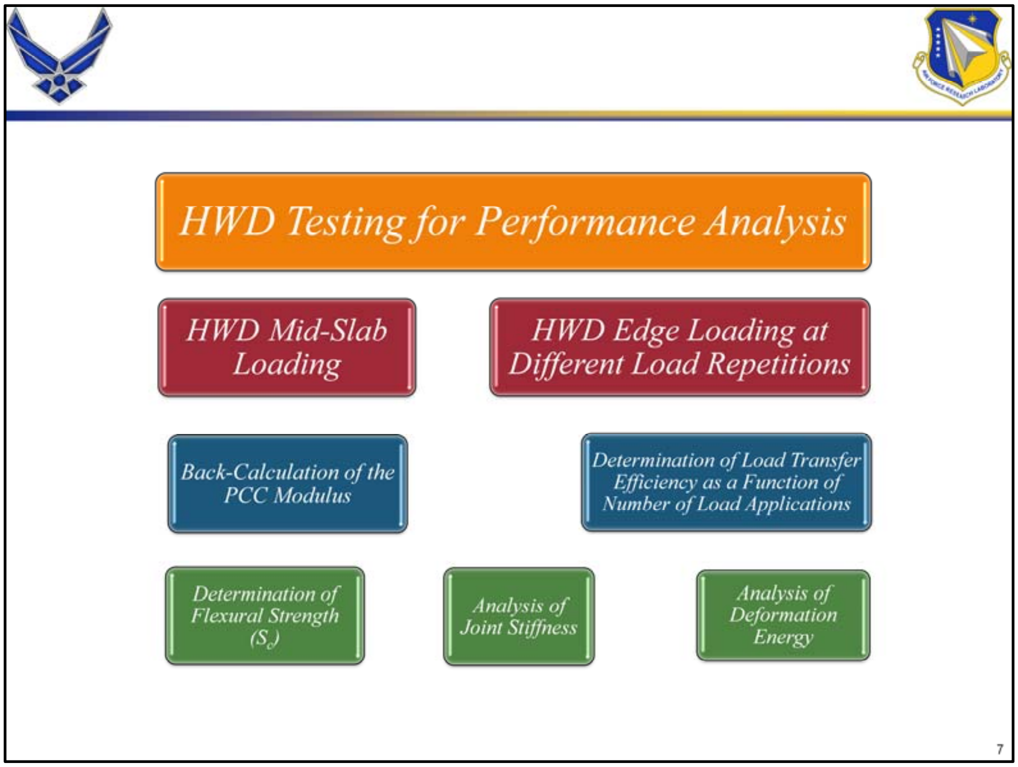
-Recast fabrication: rigid form ensures that the placed concrete maintains its dimensions and dowels maintain their orientation.

-Inserting swift lifts for proper transportation and installation, two types: et set or attached in-place on a cored hole prior to placement.

-Foundation preparation (drilling port holes for HDP foam injection and leveling) or placing the flowable fill.
--Leveling



Multiple injection ports and precise leveling equipment were considered to ensure that the precast repair panel is even with the adjacent concrete slab. The injection ports are grouted after successfully leveling the precast panel.


HWD Testing for Performance Analysis
HWD Mid-Slab Loading
HWD Edge Loading at Different Load Repetitions
Back-Calculation of the PCC Modulus
Determination of Load Transfer Efficiency as a Function of Number of Load Applications
Determination of Flexural Strength (S_c)
Analysis of Joint Stiffness
Analysis of Deformation Energy
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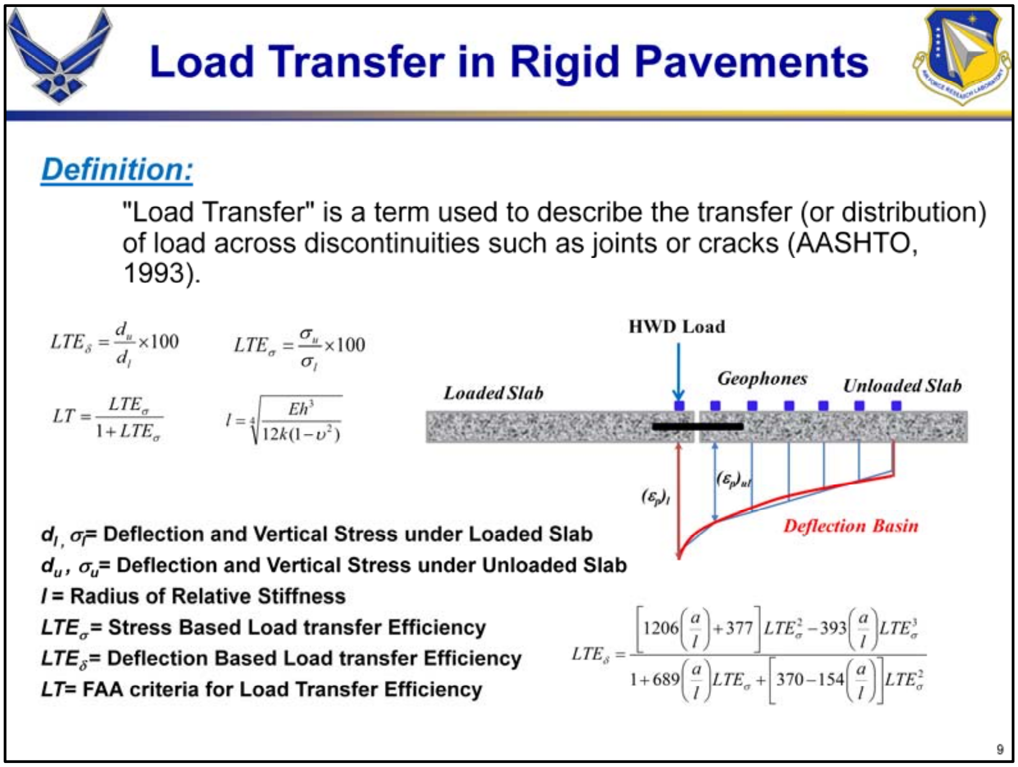
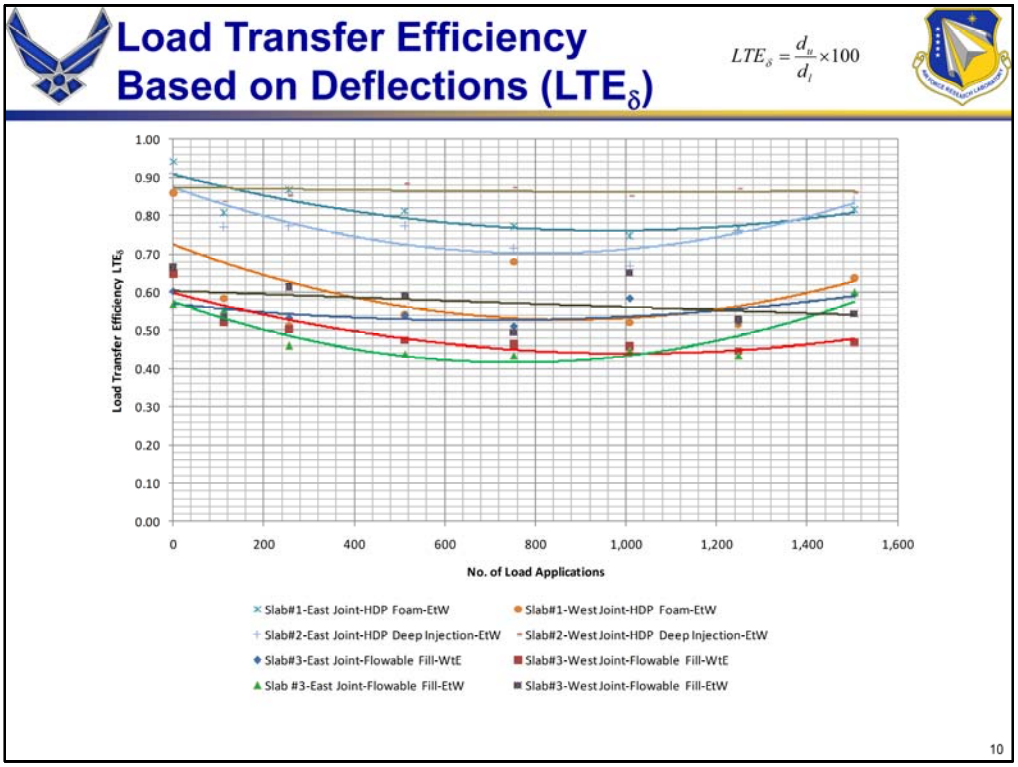
Following installation, each of the repair slabs was subjected to accelerated loading testing using the F-15 load cart. At pre-determined intervals during the accelerated loading process, a heavy weight deflectometer (HWD) was utilized to measure load transfer between the pre-existing slabs and the precast concrete repair panels. The recorded responses and layer thicknesses were later used to back-calculate the modulus values of each layer. This information was used to mechanistically determine the structural capacity and the effectiveness of the repair methods.

This slide shows the placement of the HWD at the joint for determination of LTE. This slide shows the impact load is located at the edge of the loaded slab at the right side of the picture and geophones were placed 12 inches apart on the unloaded slab.

Shows the loading channels and the F-15 load cart used to traffic the pre-cast repaired panels. This loading cart carries 35,200 lbs on a single wheel, representing one-half of F-15's main landing gear, with approximately 315 psi tire pressure.



Due to the discontinuity in the continuum, the gradient of the deflection basin changes significantly at two sides of the joints. Proper design and installation of load transfer devices will reduce the rate of change in gradient of the deflection basin. Larger differences between the slope of the deflection basin at two sides of the slabs is an indication of poor load transfer or loss of foundation support. Conversely, deflection basin of pre-cast panels showing minimal discontinuity at two sides of the joint corresponds to ideal load transfer capability of the slab-foundation systems.

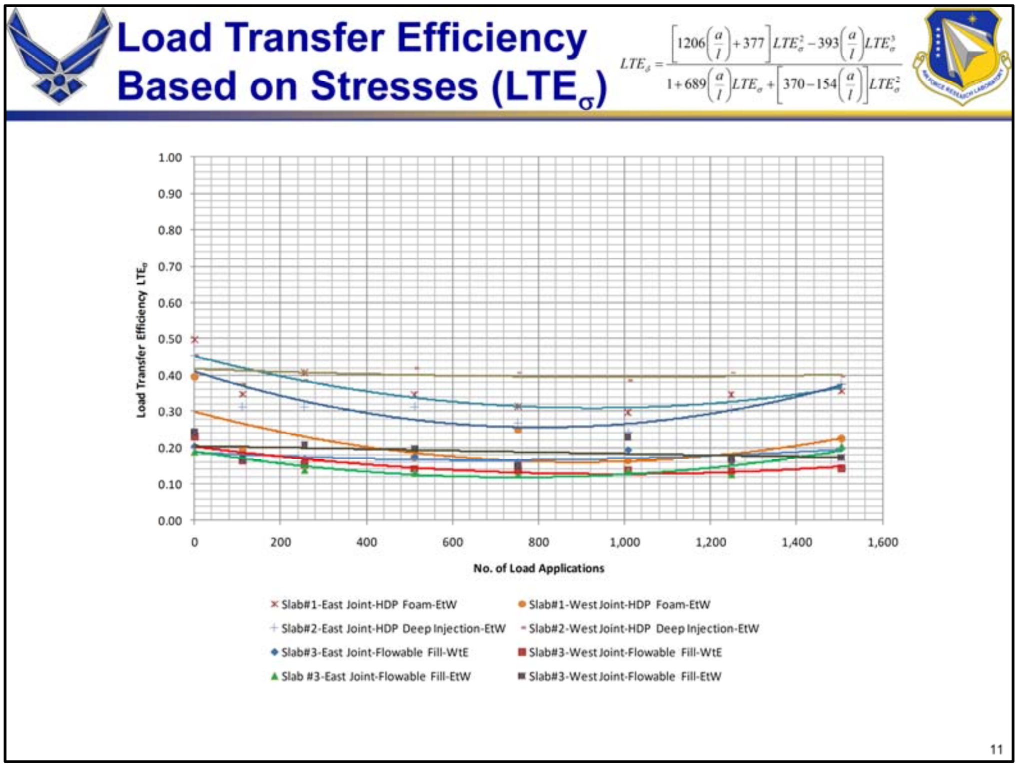


This slide presents the trends of LTE_d based on direct measurements of plastic deformations using HWD.

The measurements were taken at both sides of the joint. In other words, at each load interval, the HWD was placed at each side of the joints and directional load transfer efficiencies were determined.

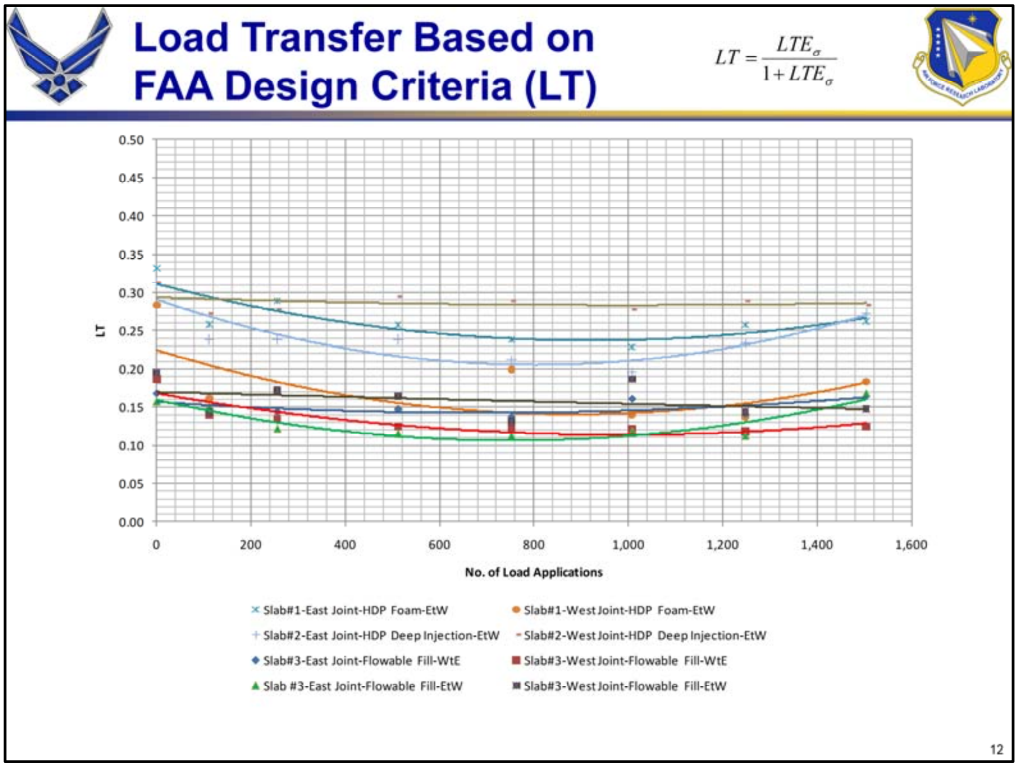
As illustrated in this slide, load transfer at the west joint of Slab #2 installed with the deep injection method had the highest value of load transfer efficiency throughout the testing period. The calculated values of the deflection based load transfer efficiency satisfy the requirement set by MEPDG .

Slab #1 with high-density polyurethane as bonding agent ranked second. Slab #3 with flowable fill was found to perform worst compared to the other design variants.



This slide shows the results for load transfer efficiency LTE_s based on the stress ratios. The results indicate that Slab #2 outperformed Slab #1 and Slab #3 in terms of higher LTE_s values. Similar to the deflection-based load transfer efficiency, west joint of Slab #2 had consistently high values of LTE_s at various loading intervals.

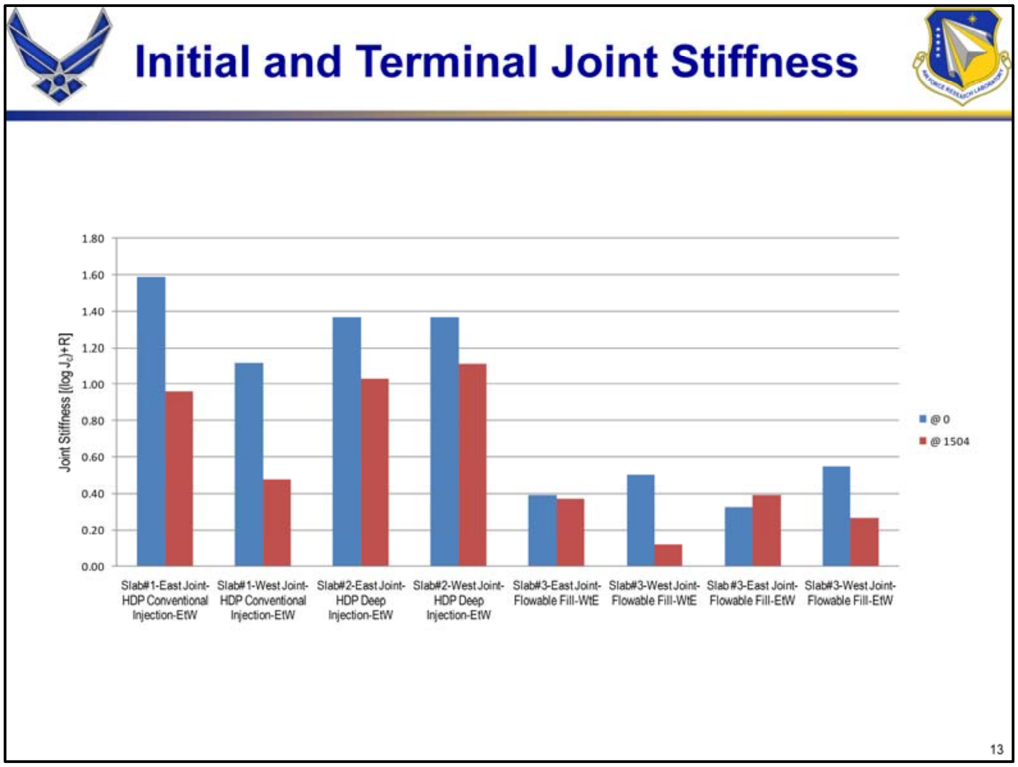
Slab #3 with flowable fill had the lowest load transfer efficiency compared to its counterparts. Repaired sections with higher values of load transfer efficiency are expected to perform better in terms of orthogonal load-bearing capacity.



Another stress-based load transfer efficiency criterion is LT defined by Federal Aviation Administration (FAA).

According to the FAA design guide, the acceptable value for LT is 0.25. The design should be revised if the load transfer does not meet this requirement.

This slide shows the LT values calculated using equation shown in the left side for the experiment design permutations. The results indicate that Slab #2 performs better in terms of load transfer (LT) compared to the other counterparts. Slab #1 rank second and Slab #3 with flowable fill performs significantly lower compared to slabs with HDP foam.



Comparison between initial and terminal joint stiffness:

This slide shows initial joint stiffness and joint stiffness after 1504 load applications. This plots again confirms that slabs installed with high density polyurethane have better initial and terminal joint stiffness compared to Slab #3 installed with flowable fill as bonding agent.

Stiffness of the joint is related to aggregate interlock (through friction forces between particles) and also the dowel actions.

This slide shows the joint stiffness values of the design variants after 1504 applications of F-15 load cart. The joint stiffness was assumed to be a function of aggregate interlock and load transfer devices such as dowel bars in the precast panels. The results indicate concrete panels installed by heavy density foam as bonding agent performed better in terms of higher joint stiffness compared to variants installed with flowable fill. On the other hand, Slab #2 was found to have higher joint stiffness compared to Slab #1 and Slab #3. This suggests that Slab #2 that is installed using the deep injection method performed better compared to the other permutations of the design experiment.

Stability of joints and its resistance to orthogonal movement is an important factor that influences the load transfer capability of the repaired sections. There are three load transfer mechanisms perceived for precast repair sections:

- Load transfer through aggregate interlock
- Load transfer through reinforcement (dowel bars)
- Load transfer through foundation support

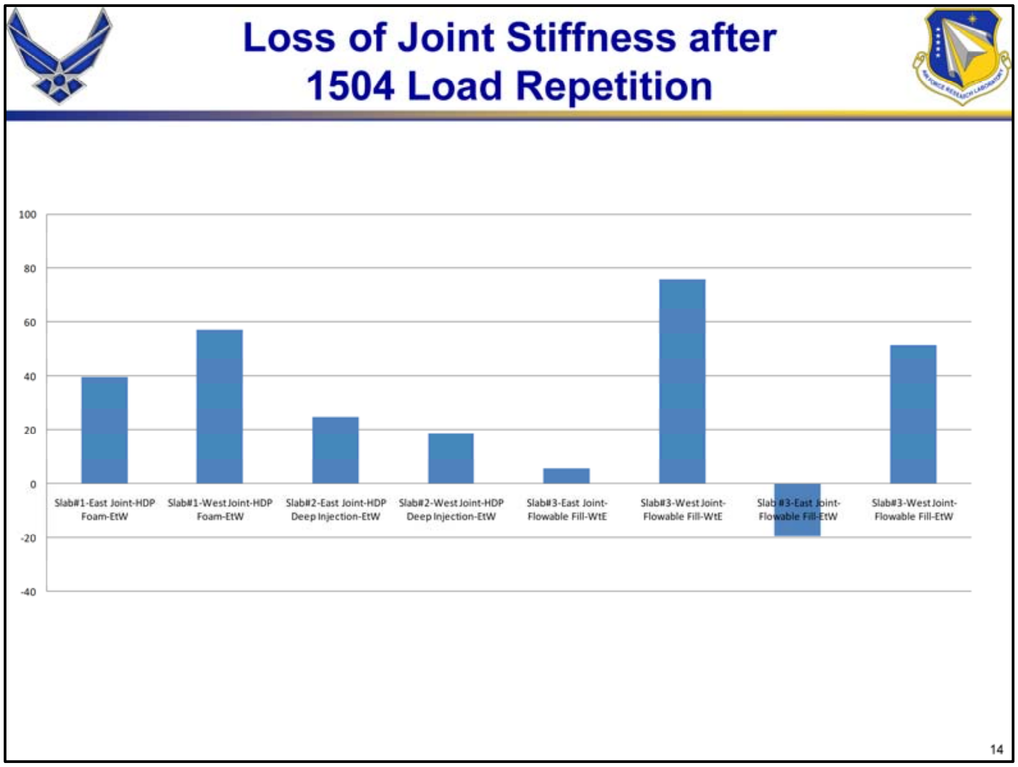
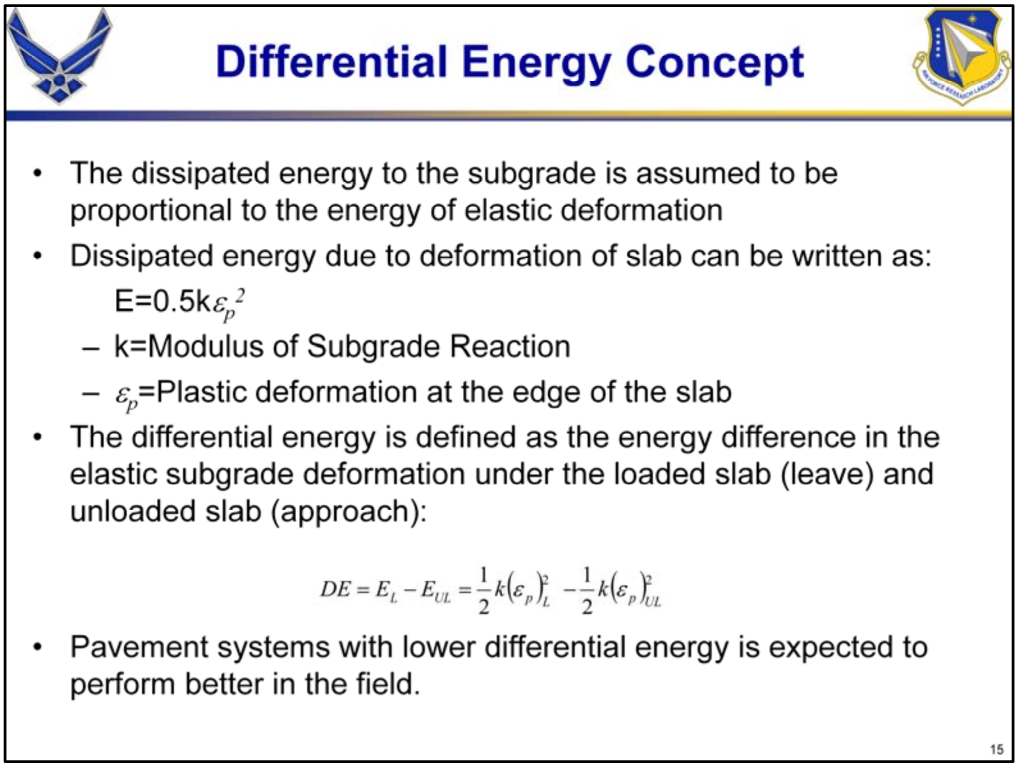
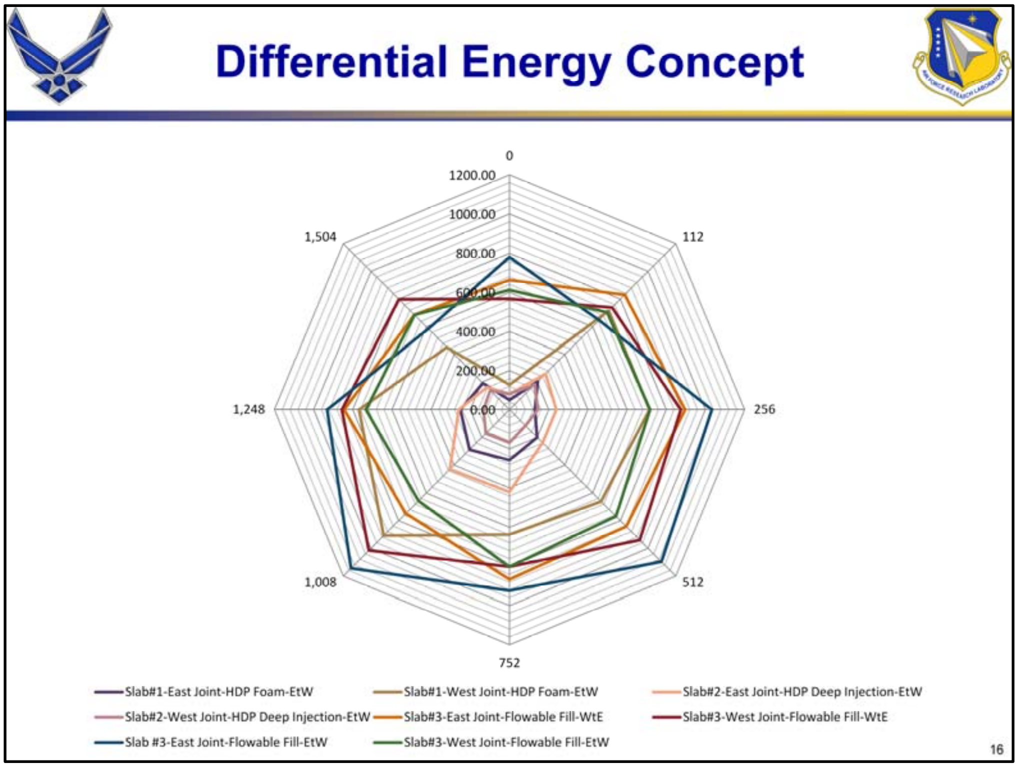


Figure 46 shows the percentage loss of joint stiffness due to 1504 load applications. This plot suggests that deep injection method resulted in better systems in terms of smaller loss of joint stiffness. In other words the gradient of the loss of stiffness in precast panels with high-density polyurethane foam and installed with the deep injection method is smaller than the other counterparts. The results pertaining to joint stiffness were found to be in conformity with the LTE and LT results presented in previous slides.



Loss of foundation support is an important factor responsible for the degradation of the performance in repaired sections. Non-homogeneous plastic deformation induced by aircraft loads at the top of the subgrade results in differential settlement and therefore loss of subgrade support, which results in degradation of load transfer in repaired sections. Quantification of the amount of deformation energy dissipated to the subgrade soil was archived through using energy equations for each variant of the experiment design. Slab-joint systems with lower dissipated energy are less prone to loss of foundation support and therefore are expected to perform better in the field.



This slide shows Slab #2, west joint installed with deep injection method has the smallest polygon area and therefore performed better in terms of dissipated deformation energy. After polygon referring to Slab #2 at west joint, areas of the polygons corresponding to Slab #1 have smaller area compared to other permutations of the experiment design as illustrated in Figure 47. This suggests that Slab #1 at both east and west joints performed superior in terms of lower deformation energy. Slab #3 was found to have the highest area compared to other variants and therefore ranked last in terms of performance based on deformation energy.

Effects of Environmental Conditions

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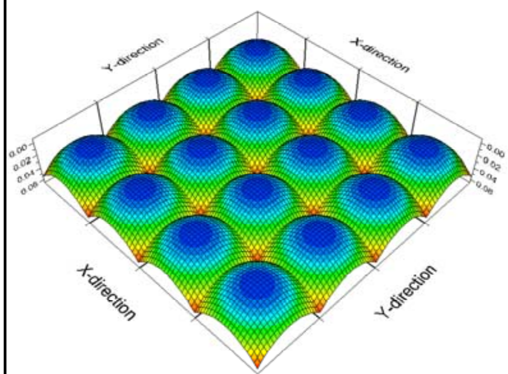
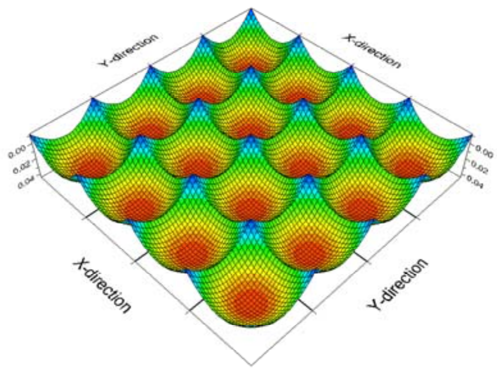
Typical Day Time Curling

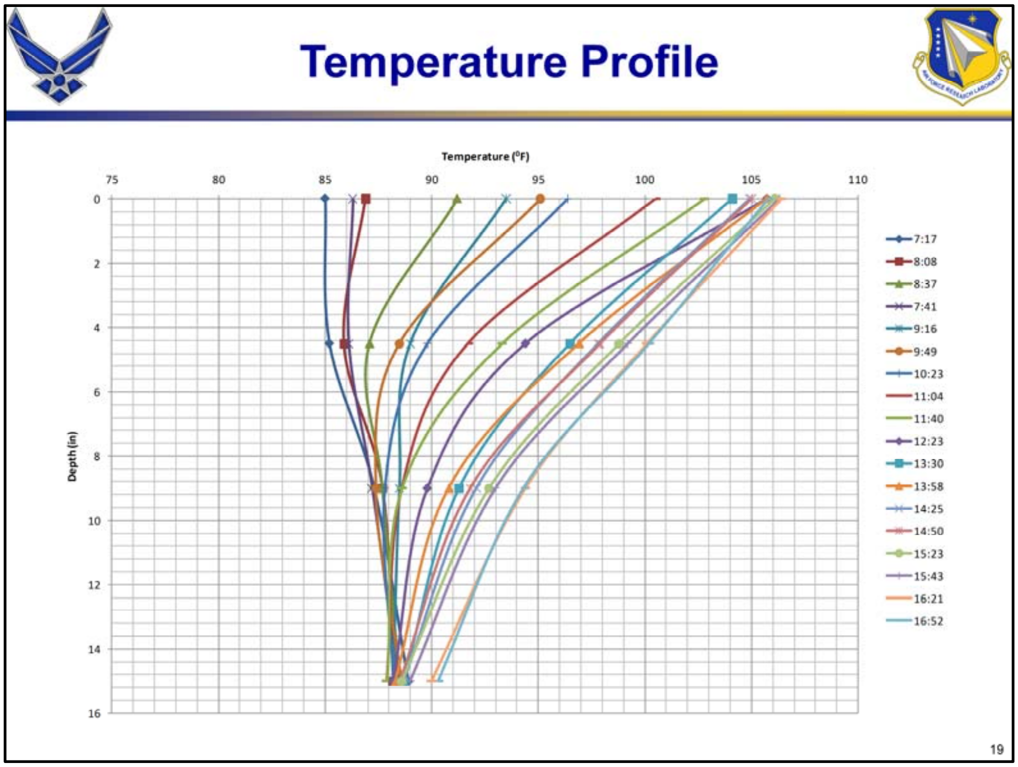


Top of the PCC Layer is *Warmer*
Bottom of the PCC Layer is *Cooler*

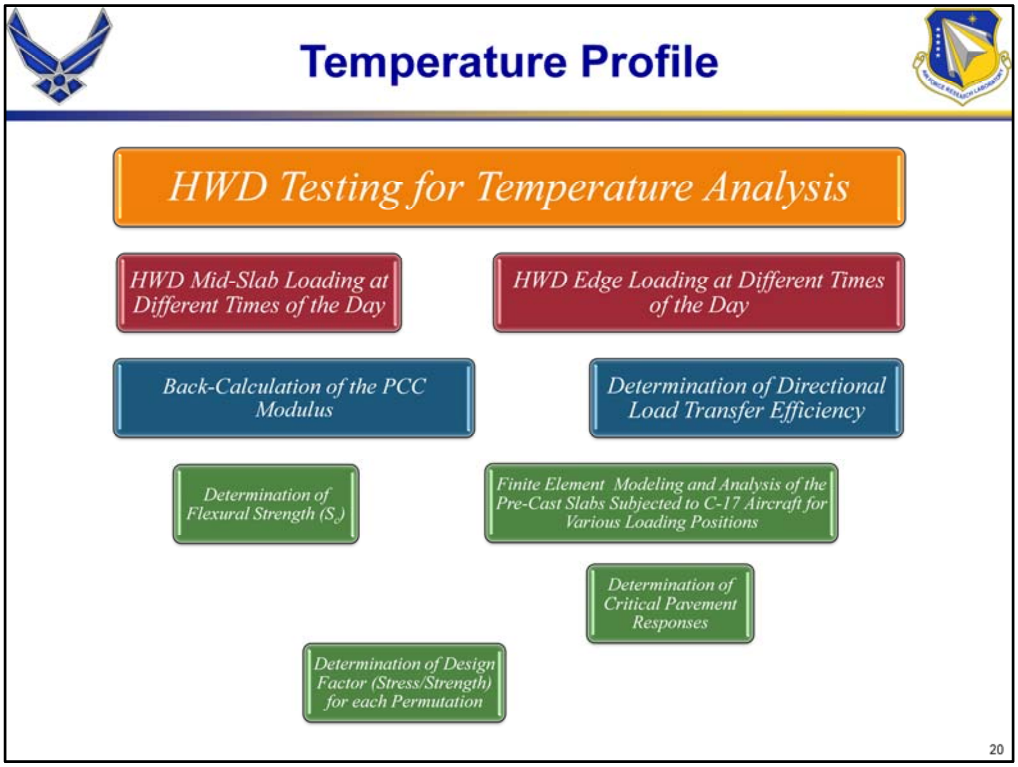
Typical Night Time Curling



Top of the PCC Layer is *Cooler*
Bottom of the PCC Layer is *Warmer*

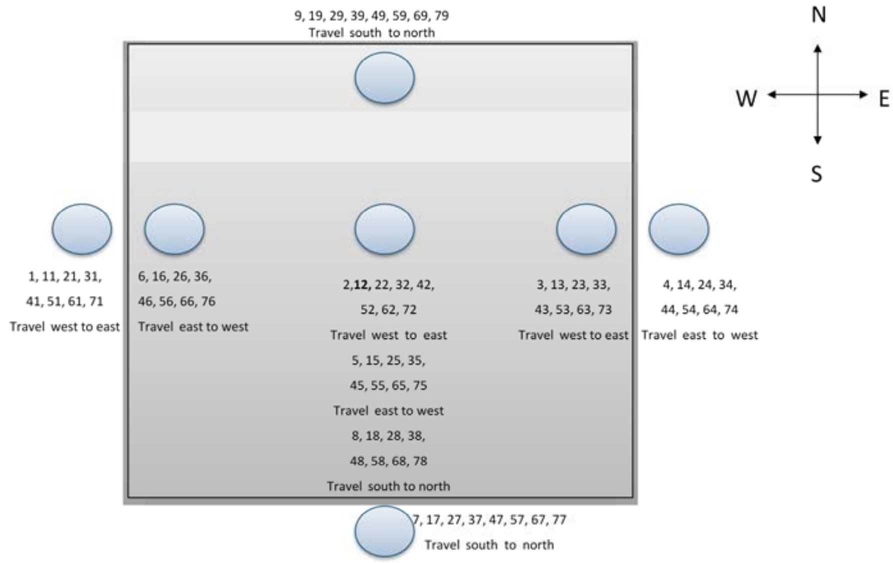


Temperature profile in the pavement



Work flow for the analysis methodology.

HWD TEST DROP SEQUENCE



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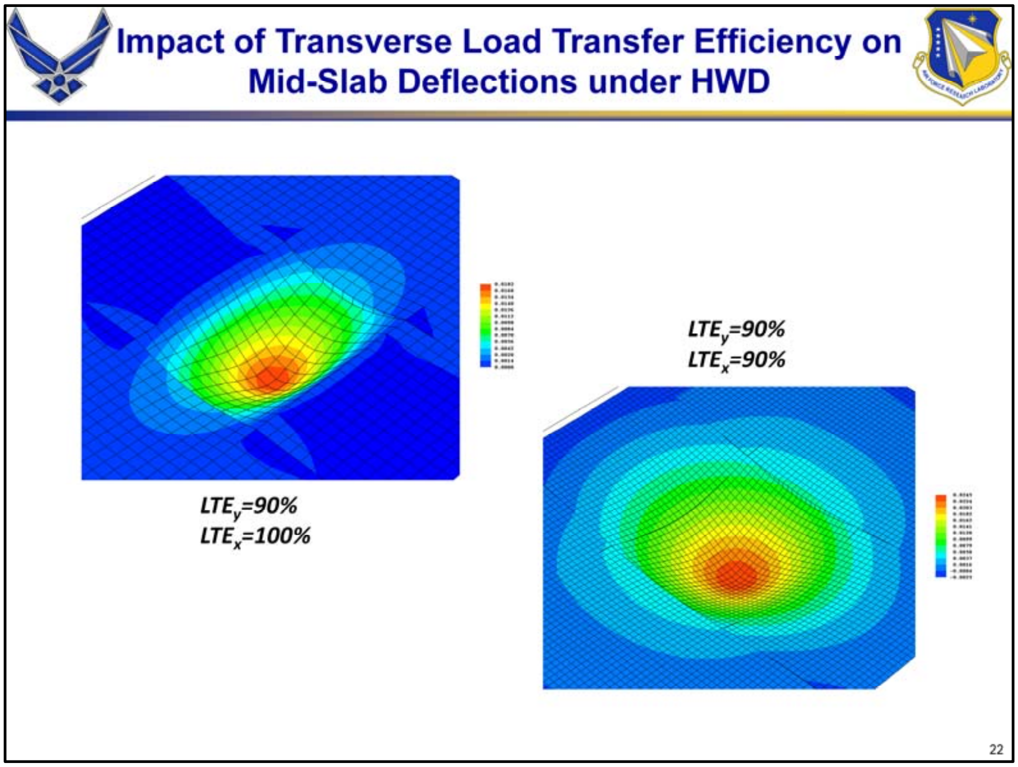
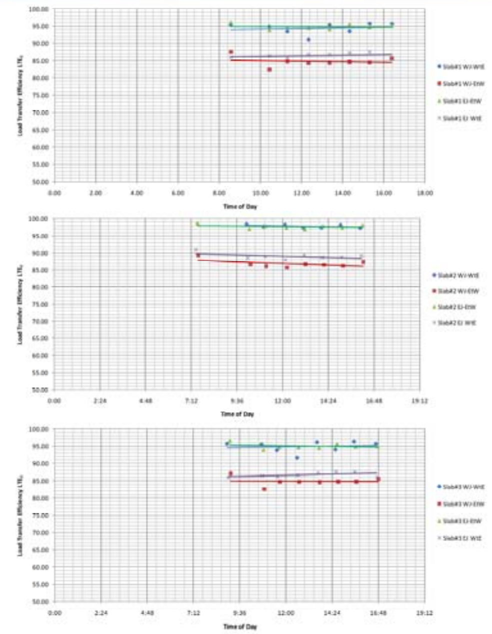


Figure 5 shows the significance of considering load transfer efficiency in X-direction and its impact on the calculated responses using finite element approach. Figure 5a shows the contour plot of the plastic deformations at the surface of the concrete when LTE_x is considered to be 100 percent. Figure 5b shows the same simulation but when the load transfer efficiency in X-direction is reduced to 90 percent. This figure suggests that maximum deflection under the HWD load at the center of the slab has increased about 26% when load transfer efficiency in X-direction reduced from 100% to 90%. This clearly indicates the significance of the impact of load transfer efficiency perpendicular to the direction of travel on the distribution of the loads in pre-cast panels.

Temperature Dependency of the Load Transfer Efficiency in Pre-Cast Panels

- Load Transfer Efficiencies were calculated as a function of time of the day and the temperatures were logged at each interval.
- Lowest recorded surface temperature was at 7:17 am as 85 ^{0}F and highest surface temperature was 107 ^{0}F at 13:57 pm.
- Load transfer efficiencies were relatively constant throughout the day.



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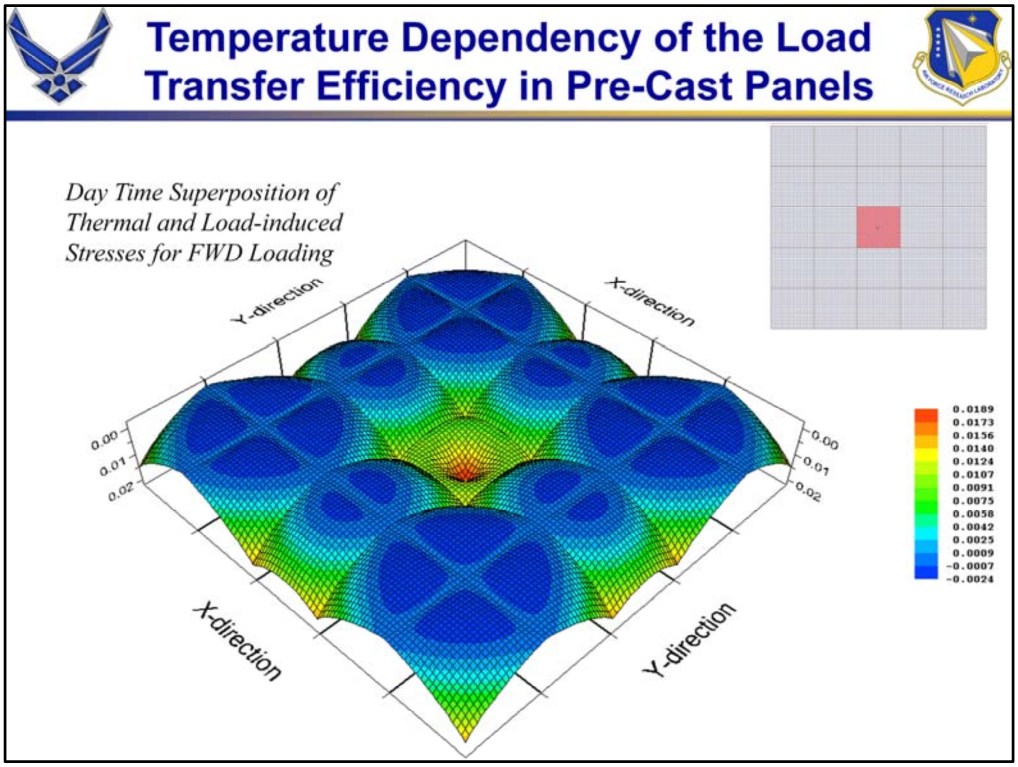
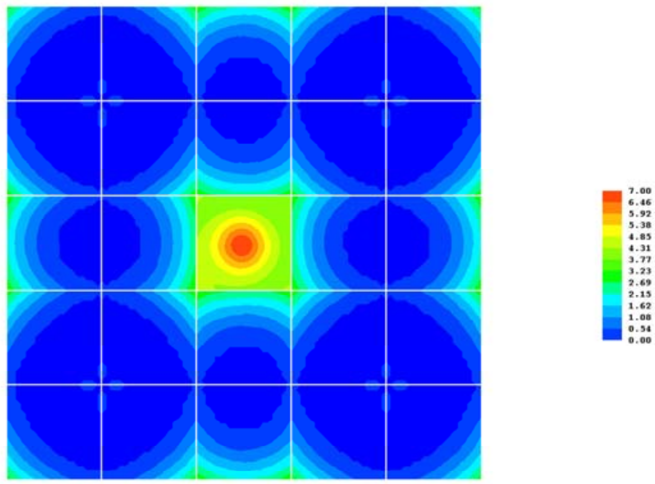
Impact of temperature on load transfer efficiency.



Superposition of thermal stresses and load induced stresses.

Distribution of Vertical Stresses at the Top of the Subgrade (Day Time)



Criteria for Different Runway Repair Strategies

- ***EXPEDIENT REPAIR***

  Expedient repairs are defined as airfield pavement repairs that create an initial operationally capable MOS/MAOS, based on projected mission aircraft requirements, in the most expeditious manner possible.

  - Criteria: Criteria have been established for an expedient repair to provide an accessible and functional MOS/MAOS that will sustain ***100 passes of C-17*** with a gross weight of 227,707 kg (502 kips), or ***100 passes of C-130*** with a gross weight of 79,380 kg (175 kips).

- ***SUSTAINMENT REPAIR***

  Repair efforts designed to upgrade expedient repairs for increased aircraft traffic are known as sustainment repairs.

  - Criteria: Sustainment repairs to an MOS/MAOS are expected to support ***5,000 passes of C-17*** with a gross weight of 227,707 kg (502 kips), or ***5,000 passes of C-130*** with a gross weight of 79,380 kg (175 kips).

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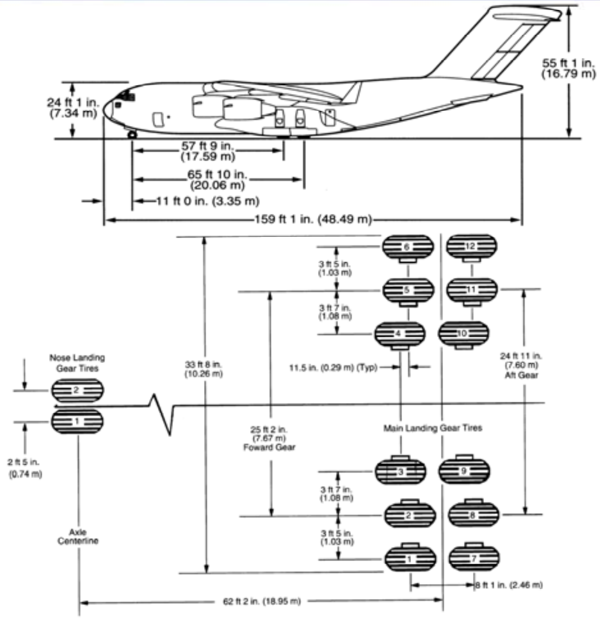
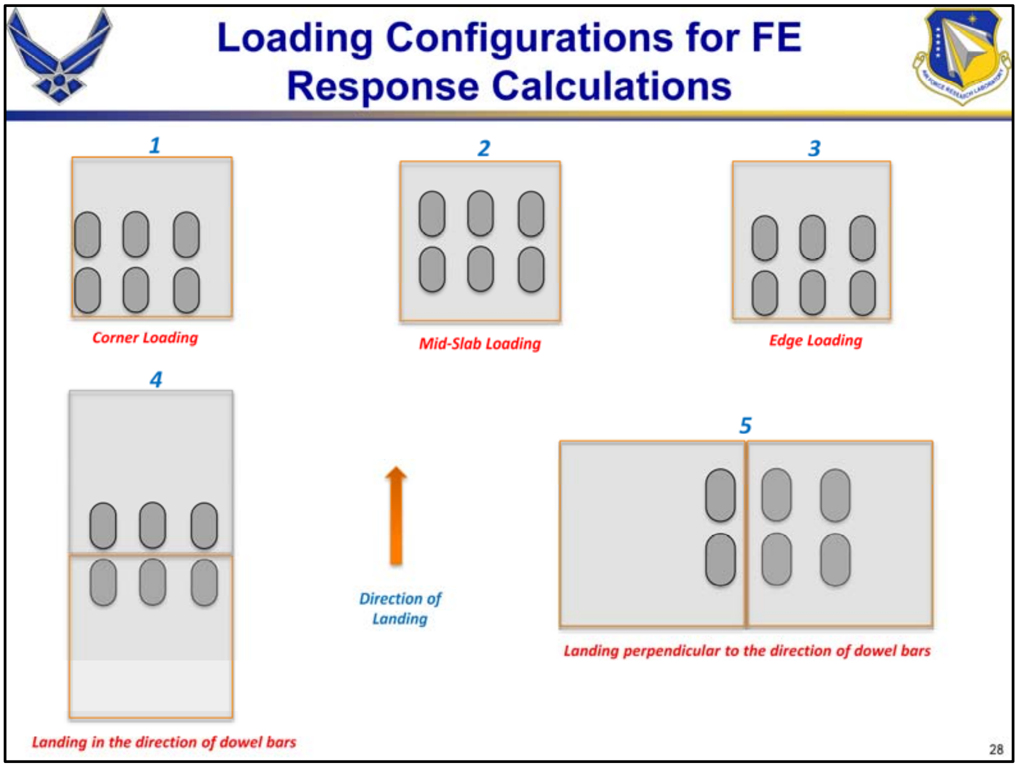
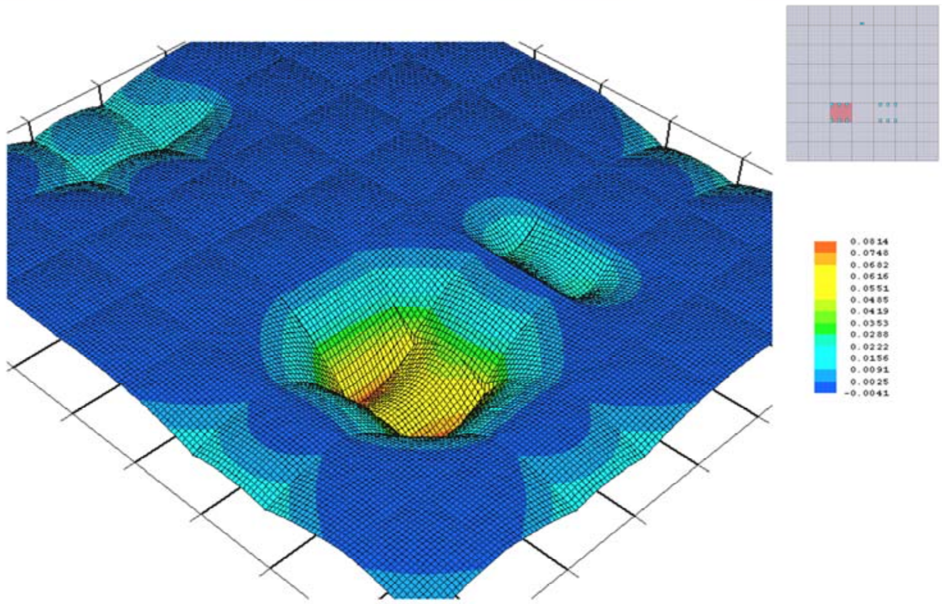


24 ft 1 in.
(7.34 m)
55 ft 1 in.
(16.79 m)
57 ft 9 in.
(17.59 m)
65 ft 10 in.
(20.06 m)
11 ft 0 in. (3.35 m)
159 ft 1 in. (48.49 m)
3 ft 5 in.
(1.03 m)
3 ft 7 in.
(1.08 m)
Nose Landing
Gear Tires
33 ft 8 in.
(10.26 m)
11.5 in. (0.29 m) (Typ)
24 ft 11 in.
(7.60 m)
Aft Gear
25 ft 2 in.
(7.67 m)
Foward Gear
Main Landing Gear Tires
2 ft 5 in.
(0.74 m)
3 ft 7 in.
(1.08 m)
3 ft 5 in.
(1.03 m)
Axle
Centerline
8 ft 1 in. (2.46 m)
62 ft 2 in. (18.95 m)

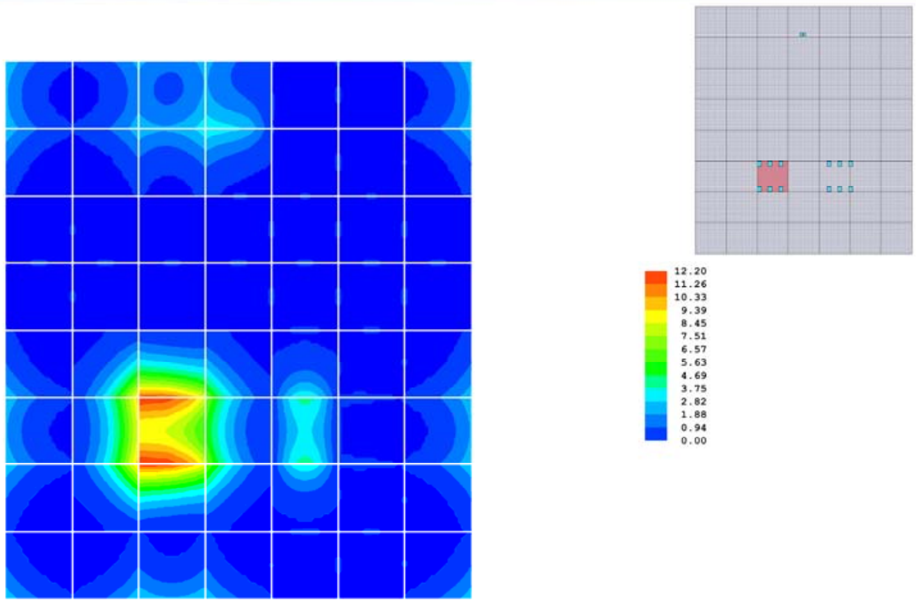
27


Loading Configurations for FE Response Calculations
1
Corner Loading
2
Mid-Slab Loading
3
Edge Loading
4
Landing in the direction of dowel bars
Direction of Landing
5
Landing perpendicular to the direction of dowel bars
28

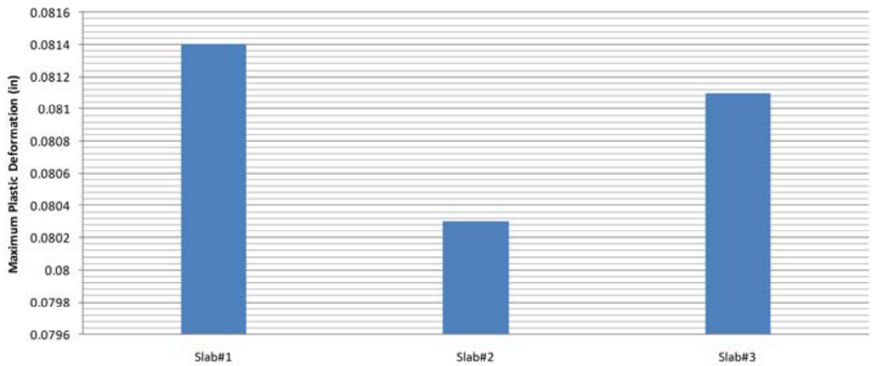

0.0814
0.0748
0.0682
0.0616
0.0551
0.0485
0.0419
0.0353
0.0288
0.0222
0.0156
0.0091
0.0025
-0.0041

29

Distribution of Vertical Stresses at the Top of the Subgrade (Corner/Edge Loading for Slab #1)



Maximum Deflection under C-17 Landing Gear



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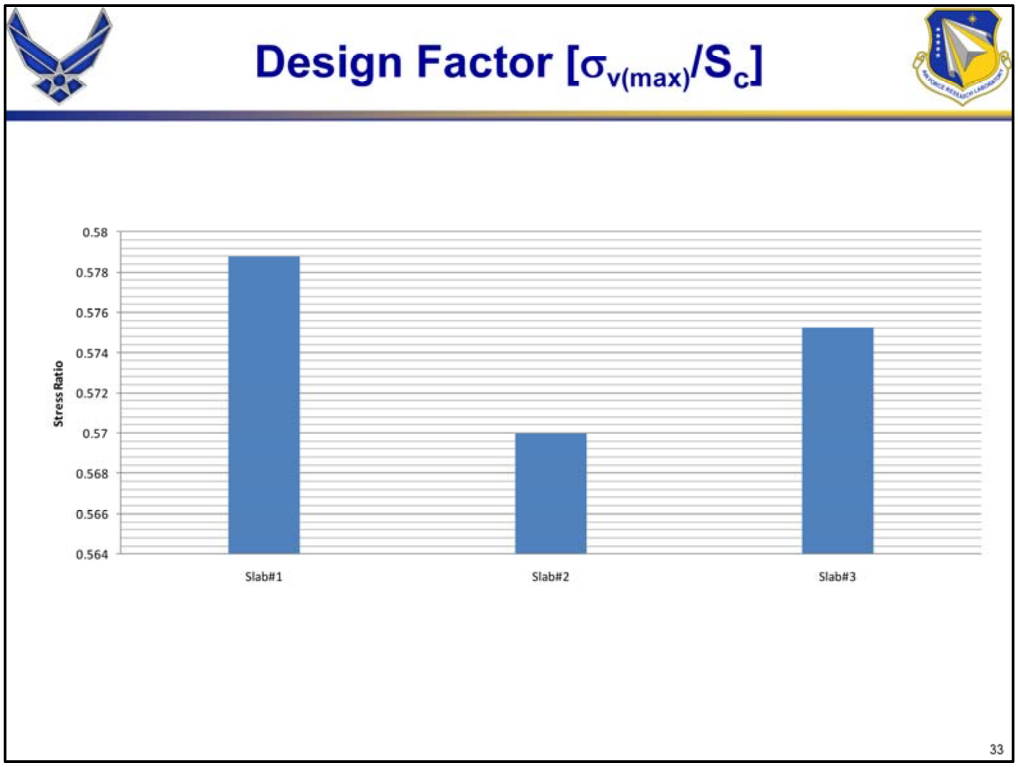
Airfield Pavement Failure Models

- **Pavement Life is a function of the ratio between flexural strength and the bending stress used in the design (AC150/5320-6D)**

$$SCI = \frac{\left(\frac{S_c}{\sigma_v}\right) - 0.2967 - F_s(0.3881 + F_{SC}\,0.000039 \times SCI)\log COV}{0.002269}$$

$$COV = 5000 \times 10^{\frac{\left[\sqrt{\frac{S_c}{1.3\sigma_v}-1}\right]}{0.07058}} \qquad F_{SC} = \frac{0.392 - 0.3881 \times F_S}{0.0039 F_S}$$

- **COV= Coverage**
- **σ_v=Working stress in the design**
- **S_c=Flexural Strength** $S_c = 6.5\sqrt{f_c'}$
- **SCI=Structural Condition Index**



Stress/strength ratios as a measure of performance of precast slabs.

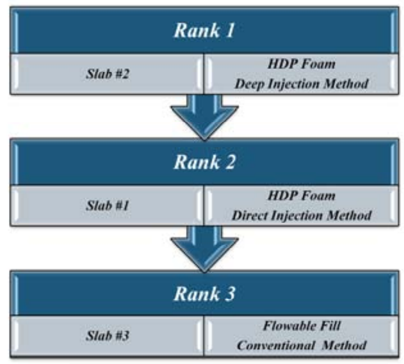
Summary

Three pre-cast PCC slab installation techniques were investigated in this research effort

High Density Polyurethane (HDP) foam was used for leveling and installation of Slab #1 and Slab #2. Flowable fill was used for Slab #3

Performance of the repaired sections were assessed through analysis of:

- Load Transfer Efficiency Based on Deflections (LTE_{δ})
- Load Transfer Efficiency Based on Stresses (LTE_{σ})
- Load Transfer Based on FAA Design Criteria (LT)
- Analysis of Joint Stiffness based on MEPDG criteria [log $(J_c)+R$]
- Analysis based on Dissipated Deformation Energy to Subgrade
- Analysis of Responses of Pre-Cast Panels using FE



Thank you!

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